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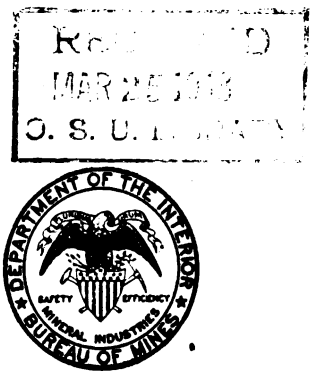
SPONGE IRON IN JAPAN



BY

THEO. L. JOHNSTON

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UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

SPONGE IRON IN JAPAN[1/]

By Theo. L. Johnston[2/]

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INTRODUCTION[3/]

In preparing for war, Japan built an iron and steel industry that ranked ıigh with other industrial nations. Deficient in raw materials for making ıron and steel, it had to acquire the bulk of its iron ore and much of its ɔoal and scrap iron from foreign sources. Steel manufacture and fabrication, ıowever, were reserved mostly for the Home Islands, where modern integrated ɔlants produced the implements of war.

The vulnerability of relying on imports during the war was recognized ɐarly, and steps were taken to exploit iron-ore deposits and develop treat-ıent processes on the Home Islands in order to be as self-sufficient as possible.

1/ The Bureau of Mines will welcome reprinting of this paper provided the following footnote acknowledgment is used: "Reprinted from Bureau of Mines Information Circular 7440."

2/ Metallurgist, Laramie, Wyo., Sponge-Iron Pilot Plant.

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Although the industry had expanded considerably, the capacity of the large plants still was insufficient for military requirements, so other methods of producing iron and steel were adopted, which in some ways illustrate the desperate effort made to supply the war machine.

In developing the iron and steel industry, modern practices of other countries were studied and followed with modifications to suit Japanese conditions. German and American technical ability and equipment played a large part in the program; however, the Japanese had competent furnace technologists capable of obtaining proper equipment performance.

For the most part, the standard practice consisted of smelting iron ores in blast furnaces and then refining the pig iron to make steel in open-hearth furnaces. Electric furnaces played an important part, especially in the manufacture of alloy steels. Various other methods yielded minor but significant production.

Among the various other treatment processes used, the production of sponge iron in rotary kilns probably was the most important in producing melting stock for steel making. Of special importance was the fact that sponge iron made from low-grade ores contained critical metals, such as nickel and chromium, so that the results were more significant than was generally believed.

IRON ORE

Prior to the time when Japan's imports were restricted by the war, approximately 80 percent of the iron ore used was imported. When interference with shipping began to be felt, production from mines on the Home Islands was increased to compensate for the lack of imports. Two principal mines, the Kuchan mine on the island of Hokkaido and the Kamaishi mine in northeastern Honshu, accounted for 70 percent of the domestic production, the remainder coming from small scattered deposits of limonite, hematite, and magnetite. A comparatively large amount of these domestic ores was not the hard lump ore desired for blast furnaces but was soft, fine-sized material that often resembled clay and therefore required treatment before entering the blast furnace. The practice of sintering these ores was followed at all large integrated steel plants; this consisted of mixing the ore with coke breeze and flue dust, then treating the mixture in a sintering machine, which yielded porous masses of semi-fused sinter or clinker suitable for the blast-furnace charge. Dwight and Lloyd continuous sintering machines, Greenawalt pans, and A. I. B. round pans were used with the batch pans preferred because of simple design and operation. Normally, about 20 percent of the ore entering the blast furnaces was sintered, but during the latter part of the war, as much as 60 percent was used when imported lump ores were scarce, and domestic ores were substituted in increasingly larger quantities.

Some of the small scattered deposits of low-grade iron ores normally would not be considered as ores, but because they contained small amounts of nickel or chromium they were exploited, and the treatment products were used in making alloy steels.

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Iron-bearing beach sands and pyrite calcines also were used as sources of iron. The beach sands usually contained titanium, which limited the amount that could be mixed with other ores; the pyrite calcines were extremely fine and contained some sulfur.

TREATMENT PROCESSES

For many years the Japanese had studied and investigated methods for treating and recovering iron from their soft ores and beach sands. A considerable amount of research work on sponge iron was performed by capable Japanese technicians, but no commercial process was developed by them.

In 1926, a 100-ton plant using the American Thornhill-Anderson revolving hearth-type furnace was erected at Kuji, Japan to make sponge iron from beach sands. After two years of operation, it was considered unsatisfactory and was dismantled. The Basset process followed a similar pattern. In 1938, the German Krupp-Renn process was adopted and resulted in the erection and operation of eight plants in Japan, one in Korea, and two in Manchuria. Brick and pottery kilns were used, also, to make sponge iron by the Swedish sagger method, but results as a whole were unsatisfactory due to poor raw materials. Several types of electric furnace processes were used of which the high-frequency method was the most noteworthy. All plants ceased operations in August 1945 and have not operated since.

KRUPP-RENN PROCESS

This process consists of heating a mixture of iron ore and coal or coke in a rotary kiln and producing iron pellets and slag. The iron pellets (called luppe) are cleaned of slag and used as melting stock to make steel. The process is adaptable to low-grade ores and coals, but costs are usually high, and the product is generally inferior to pig iron made in blast furnaces. Rotary kilns similar to those used in the cement industry are used for this process.

The Japanese plants used anthracite coal from Korea as the reducing agent and pulverized domestic subbituminous coal for firing the kilns. Most of the ores treated were low-grade limonites; iron-bearing beach sands were tried but discontinued because of their high titanium content.

Typical Japanese operation of rotary kilns consisted of charging a mixture of 100 parts iron ore, 56 parts anthracite, and 10 parts limestone, each crushed to approximately one quarter of an inch, into the kiln at the rate of 3 to 6 metric tons per hour. As the charge passed through the kiln, the reaction between the anthracite and iron ore yielded pellets of metallic iron mixed with semi-fluid slag. A temperature of 1,250° to 1,350° C. was maintained in the discharge end of the kiln. When the iron and slag mixture was discharged from the kiln, it was quenched with water, crushed, ground in a ball mill, screened, and then magnetically treated to recover the iron pellets (luppe) from the slag. In some cases, Wilfley-type concentrating tables were used for cleaning the pellets as they came from the magnetic separator. The finished product represented about 85 percent of the iron in the ore and consisted of a small number of large nodules up to 3 inches in cross section, but the major part

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(80 percent) was less than one-quarter of an inch in size. The product was then melted alone or with scrap iron and refined into steel in electric arc furnaces. It was seldom used in open-hearth furnaces.

The Japanese built 8 plants containing a total of 19 rotary kilns on their home islands. In addition to these, they constructed a large plant in northern Korea containing six large rotary kilns and two plants in Manchuria containing four and two kilns, respectively. The first plant was built in 1938 and operated under German supervision, but thereafter no outside aid was used. All plants using the Krupp-Renn process paid royalty to the Germans. Several of these plants were visited, but none were seen in operation.

The accompanying tables summarize the pertinent data of the rotary-kiln plants in Japan, Korea, and Manchuria. Table 1 lists the plants, locations, number and size of kilns, rated capacity, ore treated, product, and typical analyses of products. It is to be noted that most of the plants produced what they call "nickel-luppe," containing nickel and chromium. Annual production of each plant for 1939 to 1945, inclusive, is listed in table 2 and shows a total of 646,386 metric tons, of which 294,744 metric tons were produced on the Japanese home islands. The large plant in Korea, where high grade ore was available, produced approximately 40 percent of the total. Confusion at the end of hostilities in 1945 resulted in missing data for that year, so the grand total was somewhat greater and probably approached three quarters of a million tons. This amounted to about 2 percent of the total Japanese steel production for the same period.

IWATAKI PLANT

Illustrative of the Japanese methods of treating ores in rotary kilns is the Iwataki plant of the Nippon Metallurgical Industry Co., Ltd., on the west coast of Honshu.

Ore was supplied to this plant from the Oeyama mine, 5 miles distant, and consisted of a limonitic clay formed from the weathering of serpentine. Typical analysis showed: 25 percent H_2O, 32 percent SiO_2, 13.5 percent Al_2O_3, 1.7 percent CaO, 6.8 percent MgO, 21.0 percent Fe, 0.6 percent Ni, 0.9 percent Cr, 0.05 percent Co, 0.2 percent Mn, 0.05 percent S, and 0.06 percent P.

The kilns were fired with pulverized subbituminous coal from Kyushu, whereas Korean anthracite was used for reduction. Analyses of coals used are as follows:

	Analyses, percent			
	Volatile matter	Fixed carbon	Ash	Sulfur
Coal for firing	37.9	41.5	20.2	-
Coal for reduction..	6.0	75.2	18.5	0.25

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TABLE 1. - Rotary-kiln plants, Japan, Korea, and Manchuria

Name of plant and location	Ore used	Kilns No. and size	Rated capacity ore/24 hr., M. tons	Type of product	Typical analysis of product, percent
1. Iwaki Cement Co., Ltd., Nanoa-shi, Ishikawa-ken	Limonite	1(3.45x88 m) 2(3.45x73 m)	212	Ni and Cr luppe	Fe-94.6;C-1.13;Si-0.065;P-0.097 S-0.22;Ni-1.9;Cr-1.58
2. Kawasaki Heavy Ind Co., Ltd., Kuji Town, Iwato-ken	Sandy limonite	2(3.6x60 m) 1(1.0x8 m)	152	luppe	C-1.5;Si-0.2;P-0.24;S-0.1;Mn-0.1; Ti-trace.
3. Nippon Metallurgical Ind Co., Ltd., Iwataki, Kyoto-ken	Limonite	4(3.6x70 m)	288	Nickel luppe	Fe-93.47;C-0.80;Si-0.32;P-0.113; S-0.124;Ni-2.53;Cr-1.18;Co-0.10
4. Nippon Nickel Co., Ltd., Onishi, Cumma-ken	Serpentine limonite	1(2.8x50 m)	60	Nickel luppe	C-0.8;Si-1.8;P-0.2;S-0.22; Ni-1.3;Cr-0.6;Mn-0.45
5. Nippon Iron Sand Steel Ind Co., Ltd., Hachinohe	Leached iron sands	2(2.8x50 m)	120	sponge iron	No data
6. Nippon Iron Sand Co., Ltd., Takasago, Hyogo-ken	Leached iron sands	2(1.83x27 m) 1(1.25x17 m)	72	sponge iron	No data
7. Riken Industrial Corp., Hirai, Tokyo	Limonite and imported	2(2.3x38.0 m)	72	Ni and Cr luppe	Fe-92.13;C-?;Si-1.20;P-0.05 S-0.20;Ni-1.70;Cr-2.01
8. Toa Jyukogyo-sha, Tsukiji. Fukuoka-ken	Mill scale	1(1.8x30 m)	36	sponge iron	Fe-93.0;C-0.52;Si-0.38;P-0.03 S-0.18;Mn-0.32
Japan total		19	1,012		
Mitsubishi Co., Seishin, Korea	Mosan magnetite	6(3.6x70 m)	432	luppe	Fe-95.0;C-1.0;SiO_2-3.5;S-0.15; P-0.15
Manchurian Iron & Steel Co., Anshan, Manchuria	Hematite and magnetite	4(3.0x60 m)	240	luppe	Fe-97.0;C-0.7;S-0.35;P-0.12; Si-0.6
Fushun, Manchuria	Magnetite	2(3.0x60 m)	120	luppe	No data
Grand total		31	1,804		

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TABLE 2. - Annual production of luppe from rotary kilns, Japan, Korea, and Manchuria, 1939-1945, metric tons

Name of company	1939	1940	1941	1942	1943	1944	1945	Total
Iwaki Cement Co., Ltd., Nanao City..	219	6119	11795	16416	24939	15787	2089	77,364
Kawasaki Heavy Ind Co., Ltd., Kuji City	-	-	1690	15520	23870	24260	6280	71,620
Nippon Metallurgical Ind Co., Ltd., Iwataki City	-	-	-	-	8863	20325	7785	36,973
Nippon Nickel Co., Ltd., Onishi Town.	-	298	4035	5201	1107	†	†	10,641
Nippon Iron Sand Steel Ind Co., Ltd., Hachinohe City	-	-	-	-	5280	26434	13801	45,515
Nippon Iron Sand Steel Ind Co., Ltd., Takasago Town	-	-	1784	2056	8304	5286	270	17,700
Riken Industrial Corp., Hirai,	786	2810	230	241	-	†	†	4,067 luppe
Tokyo	-	1516	3720	2313	2100	†	†	9,649 NiFe
Toa Jyukogyo-sha, Tsukiji City, Fukuoka.....	-	-	2705	5271	6171	5620	1448	21,215
Japan total	1005	10743	25959	47018	80634	97712	31673	294,744
Mitsubishi Co., Seishin, Korea....	13744	36974	51331	58513	52922	51158	†	264,642
Manchurian Iron & Steel, Anshan, Manchuria	-	13000	17000	19000	18000	20000	†	87,000
Fushun, Manchuria..	*	*	*	*	*	*	*	*
Grand total	14749	60717	94290	124531	151556	168870	31673	646,385

† Operated to August 1945, but production data not available.
* No production data; estimated to be 8,000 metric tons annually during 1942, 1943, and 1944.

The plant (see fig. 1) consisted of a group of buildings constructed of concrete, structural steel, and corrugated sheet iron. Ample storage capacity was provided for ore, coal, and limestone. Equipment for crushing, drying, mixing, and conveying raw materials was well layed out in a continuous flow scheme between the storage bins and the rotary kilns. The ore was crushed to 1 inch, limerock to $\frac{1}{4}$ inch, and the slack anthracite was used as received (less than $\frac{1}{2}$ inch). The main building housed four rotary kilns (see fig. 2) each 70 meters long and 3.6 meters shell diameter, placed parallel to each other and set at a 2-percent slope. Fire-brick lining 10 inches thick was used in the high-temperature zone and inferior brick for the remainder. The kilns rotated at one to three quarters r. p. m.

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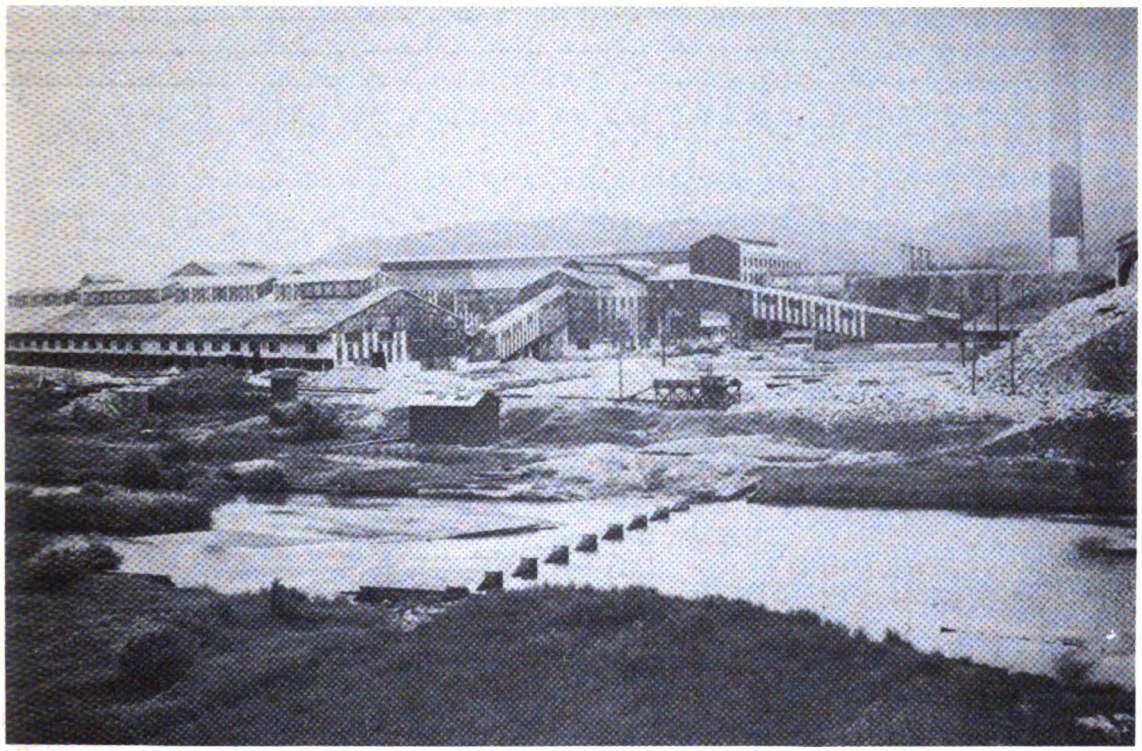

Figure 1. - Sponge-iron plant, Iwataki, Japan.

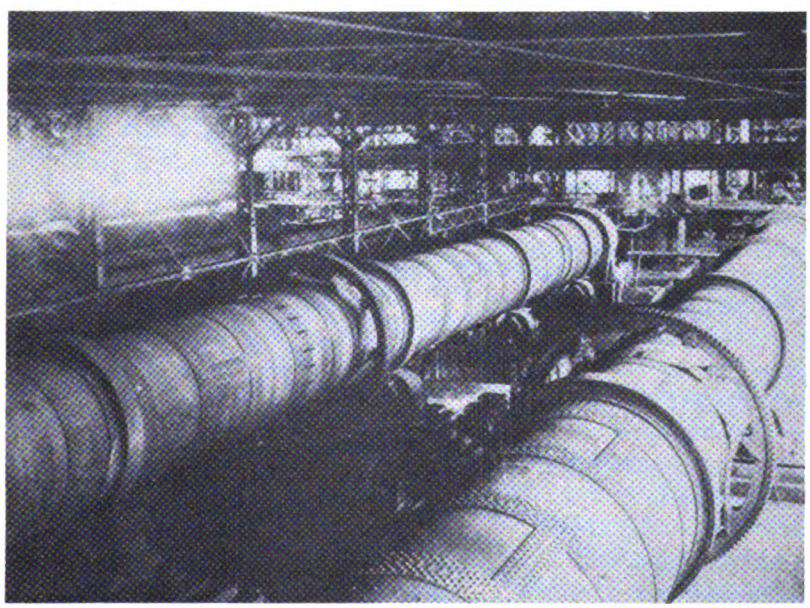

Figure 2. - Four rotary kilns of Iwataki plant.

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Pulverized subbituminous coal was blown into the discharge end of the kiln at the rate of 300 kilograms per ton of product. A simple pipe burner was used, and the air blast was not preheated. The temperature in the hot or "luppe" zone was maintained at 1,300° C., 30 meters from the discharge at 600° to 700° C., and in the dust chamber at the feed end at 250° to 300° C.

The charge to the kiln was a mixture of 100 parts ore, 25 parts limestone, 45 parts anthracite, 10 parts flue dust, and 10 parts of magnetic middling returned from treatment of the kiln product. The mixture was fed at the rate of 6 metric tons per hour. As the charge progressed through the kiln, the iron was reduced to metal and virtually all of the anthracite coal was consumed by the time the charge had moved three-quarters of the kiln length. In the high-temperature zone the reduced iron was pelletized and the waste minerals were slagged, resulting in a clinkerlike discharge consisting of a mixture of $2\frac{1}{2}$ parts of semifluid slag and 1 part of iron pellets (luppe).

The kiln discharge material dropped into a stream of water and was washed into a pit nearby. From the pit it passed through a crusher, ball mill, trommel screen, and then to magnetic separators, where the iron was separated from the slag. The magnetic product was further cleaned by tabling on a Wilfley table, from which a low-grade middling product was separated and returned to the kiln feed. Some large iron nodules were produced, but 80 percent of the final product consisted of pellets less than one-quarter inch in size. Recovery of the iron was reported to be 85 percent, but no estimate was given on nickel recovery. Typical analysis of the product of this plant is shown in table 1.

This plant had four rotary kilns but never operated more than two at one time. Many difficulties were experienced in kiln operation, which caused numerous shutdowns. Corrosion of the brick lining often warped the kiln shell. The growth of accretions or rings within the kiln was a constant hindrance to operations but was reportedly partly overcome during the last year of operation. Excessive flue dust also was a problem. As a whole, kiln operations were not too satisfactory; continuous operation seldom exceeded 60 days without repairs or clean-out, so the rated capacity was never approached.

The production of this plant is not large, as seen from table 2; however, the value of the product as a melting stock for alloy steels was very significant to Japan during the war. The product, known as nickel-Luppe, was shipped to army and navy ordnance plants and many other industries throughout Japan, where it was melted and refined into special steels in electric-arc furnaces. Gears, machine parts, special parts for autos and planes, and high-tensile-strength armor plate are some of the end products made from this iron. Typical analysis of some of the luppe steels are as follows:

Luppe steel analysis, percent

Class	C	Si	Mn	P	S	Co	Ni	Cr
1	0.28-0.40	0.35	0.6 -1.3	0.03	0.03	0.07-0.25	1.0-1.5	0.8-1.8
3	0.28-0.38	0.35	0.8 -1.5	0.03	0.03	0.07-0.25	1.0-1.5	2.5-3.5
4	0.18	0.35	0.3 -0.6	0.03	0.03	0.07-0.25	1.0-1.5	0.6-1.5
7	0.5 -0.65	0.35	0.35-0.65	0.03	0.03	0.07-0.25	1.3-1.8	0.5-0.9

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OTHER ROTARY-KILN PLANTS

Other plants in Japan followed closely the pattern of operations of the Iwataki plant, except the Nippon Iron Sand Co., which chemically treated iron sands for vanadium and recovered sponge iron as a secondary product.

The plant of the Mitsubishi Mining Co. at Seishin, Korea, was the largest in the Orient. Concentrated magnetite from the Mosan mine was reduced to luppe in six large kilns. Two more kilns were being added but were not completed by the end of the war. The product was shipped to Japan or electrically melted and refined into steel at the plant and then shipped to Japan.

In Manchuria, a four-kiln plant was operated as part of the Manchurian Iron & Steel Co. works at Anshan. The ore treated was undersize material screened from blast-furnace lump ore. Coke breeze was used as a reducing agent, and blast-furnace slag was used in place of limestone. Equipment and operations were similar to those of the Iwataki plant previously described. The product was shipped to Japan. Because of the low cost of raw materials, this plant produced luppe at a cost comparable to that of pig iron. A second plant in Manchuria, at Fushun, containing two rotary kilns, was operated for several years, but information regarding its activities and production was not available. The product was melted in electric furnaces, and the resultant steel was rolled or forged into fabricated articles in the same plant.

As a whole, the rotary-kiln plants erected by the Japanese served to treat lean ores that would not have been treated by other methods. The technique, as obtained from the Germans, was used in a standard pattern with the one object of maximum production with no time for experimental research. No new improvements in the methods were developed that could be considered as an advancement over the Germans who had developed, patented, and used the Krupp-Renn process before World War II. The most outstanding point of Japanese work was their use of this method on iron ores containing nickel and chromium and then using the product to make alloy steels in electric furnaces. This use may find application in this country.

OTHER TYPES OF PLANTS

Batch Kilns

Several brick kilns and pottery kilns were coverted to the production of sponge iron by the Swedish or sagger method, in which fine ore and carbon are placed in a clay container (sagger) and the containers heated in batches in stationary kilns. A cycle of approximately a week consisted of hand-loading the kiln with charged saggers, firing the kiln until a temperature of 1,200° C. had been maintained for 30 hours, cooling, unloading, and recovering the reduced iron cakes. Low-grade ores and poor coal were used, so the product was also of poor quality and was generally used with scrap iron, as the charge to electric furnaces in foundries making ordinary castings. Production was so erratic and the product so unsatisfactory that complete records were not kept. It is estimated that the total amount of iron produced by this method did not exceed 10,000 metric tons altogether.

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Although the use of this sagger method in the Japanese Home Islands on ɔw-grade ores may be considered virtually a failure, its use in one plant ı Penshihu, Manchuria, on high-grade ore was an exceptional success. The ınchurian Iron & Steel Co. built a small plant in connection with the large ɔrks at Penshihu, Manchuria, and produced small amounts of high-grade malle-ɔle sponge iron by the sagger method. Magnetite concentrates containing 69 ɛrcent iron, low-phosphorus coke breeze, and local limestone were the materi-ls used. The procedure consisted of mixing concentrates with 10 percent ɬaked lime and hand-forming the mixture into round cakes or briquettes 5 ıches in diameter and 1¼ inches thick and weighing approximately 2 pounds. ıe cakes were placed in fire-clay saggers 18 inches high, 6 cakes to each ıgger, and each cake surrounded with a 1-inch layer of coke breeze. One ton ? coke breeze and 100 kilograms of slaked lime were used for each metric ton ? sponge iron produced. The full saggers were loaded by hand into a station-ry brick kiln, 15 by 30 by 8 feet; the kiln was coal-fired for 2 days for pre-ɛating, held at 1,000° to 1,050° C. for 30 hours, then cooled for 4 days, and ılloaded. There were 8 kilns, and each kiln yielded approximately 8 metric ɔns of reduced iron cakes per batch. The cakes were cleaned of adhering car-ɔn and then pressed cold in a hydraulic press, which reduced the thickness ıe-half and increased the density from 2 to 4. Typical analysis of the fin-ɕhed sponge-iron cakes showed total iron, 97.2 percent; metallic iron, 96.1 ɛrcent; SiO_2, 2.4 percent; S, 0.018 percent; P, 0.008 percent; and C, 0.2 ɛrcent. These cakes were then melted in a nearby 5-ton Herroult electric ırnace and made into ingots of high-grade steel, which were shipped to the ıvy arsenal in Kure, Japan, for special use. Analysis of the ingots showed ıe following range: C, 0.11 to 0.31 percent; Si, 0.11 to 0.21 percent; P, .006 to 0.019 percent; S, 0.009 to 0.028 percent; and Mn, 0.05 to 0.21 percent.

This plant employed a large amount of hand labor but was well-organized ıd operated. It operated from 1940 to the end of the war and produced an ɣerage of 5 tons per day of finished sponge-iron cakes during that period. ɣing to the high quality of this product, it would command a premium price ıd be commercially feasible for peacetime production.

Ascending Kilns

In several localities a peculiar construction of ascending kilns was used ɔr treating limonite ore by the sagger method. It consisted of a series of to 10 connected rooms placed on a hillside and arranged so that the waste ɛat from the lower room would pass upward through the rest of the rooms. hen reduction was completed in the lower room, firing would be moved to the ırtly heated room above and successively to the last at the top; meanwhile, ɔoling and unloading could proceed from the bottom. The method was designed ɔ conserve heat and time, but it evidently was not successful, as records of roduction were not kept.

Electric Furnaces

Various methods of making iron by a direct process in electric furnaces ɛre used, and although the product was not sponge iron and the tonnage pro-ıuced was not large, the methods used were of interest and further illustrate he desperate efforts to increase the output of iron.

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Of special interest is the high-frequency electric (Kikuchi) method, in which a high-frequency current is passed through a mixture of iron ore, coal, and limestone to yield pig iron in 10 minutes. The process was reportedly developed from ancient Belgian patents and was used in five plants in Japan. Production was in batches of approximately 100 pounds each. Procedure consisted of placing a prepared mixture of iron ore, coal and coke breeze, and limestone in a long horizontal, wooden box filled with inert material. A trench cut lengthwise through the top of the inert material was filled rounded full with the mixture, so that the charge represented a cylinder about 6 inches in diameter and extending the length of the box. Buried lengthwise in the center of the charge was an iron wire for conducting electricity. The ends of the iron wire were attached to permanent cables leading from the source of the high-frequency current. When the circuit was closed, the electric current soon developed a high temperature all along the buried wire, resulting in smelting of the charge and yielding iron and slag. Action was completed in 10 minutes, the charge was allowed to cool and solidify another 10 minutes, and then was removed and replaced by another batch. The iron wire melted into the iron product of each batch. The iron product (bar iron) was a crude pig or cast iron of long, barlike shape, which was broken into short lengths weighing about 20 pounds each, cleaned of adhering slag, and used as melting stock in electric-arc furnaces. The five plants in Japan produced approximately 65,000 metric tons of iron by this method during the period 1939-1945. A large plant employing this method was built in northeastern Korea, but details of its operation and production are lacking.

Another type of electric furnace used, called the "open furnace," consisted of an open crucible or hearth, in which a charge of ore and coal was smelted by the heat generated from the arc of three electrodes immersed in the charge, and yielded iron and slag. Production was low and operations erratic.

COSTS

Records of cost of production of iron by direct methods were so involved with other operations that clear statements were unobtainable. Estimates showed that the cost was two to four times as much as the cost of producing pig iron from blast furnaces. Government subsidies played an important part in financing many of the operations, and interlocking of ownership with parent companies and subsidiaries obscured the financial status of others, so that the resulting manipulation of funds, together with Oriental accounting, made it difficult to obtain actual unit costs.

SUMMARY

Japanese efforts to increase their output of iron and steel by employing various small-scale treatment methods on low-grade domestic ores increased their over-all production appreciably.

Of the various methods employed, the rotary-kiln method was the most important and accounted for 646,000 metric tons during the period 1939 to 1945. Starting with one Krupp-Renn plant and German assistance in 1938, the use of the method spread each year, until 11 plants containing 31 rotary kilns were in operation in Japan, Korea, and Manchuria.

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Operation of the rotary-kiln plants met with many difficulties imposed by wartime conditions, which hindered production so that the rated capacities were not reached. Rated capacities, however, seemed to be a vague figure purposely set high so as to spur production. Low-grade and refractory iron ores, poor coal, labor difficulties, transportation irregularities, and general wartime restrictions all contributed to limit production.

Most of the ores treated contained small amounts of nickel and chromium, which fact was of major significance to the industry and probably accounted for the widespread adoption of the method. These elements were recovered in the product (luppe), which was made into special alloy steels in electric furnaces, thus fulfilling a need that could otherwise be met only by imports. The combination of rotary kilns and electric furnaces was developed as suitable to conditions in Japan and is considered by the Japanese as a post-war possibility of retaining part of their restricted steel industry. Plans are to develop this phase of the industry by research directed towards economic production.

The cost of producing 1 ton of sponge iron in Japan was not ascertained but no doubt was high in comparison with the cost of pig iron from blast furnaces. Considering the grade of ore to average about half the iron content of what we consider merchantable iron ores, the cost of the product would be doubled at the beginning. However, when the value of the recovered nickel and chromium is taken into account and credited against costs, a reasonable figure would be expected.

In comparison, the extent of adoption of sponge-iron methods in the United States has not passed the experimental stage except in a few small-scale operations. Conditions in the steel industry of the United States are different from those in Japan and may not warrant extensive adoption of such methods at this time. However, development of the process to the point where cost compares favorably with standard steel production would create interest, especially in localities where raw materials and electric power are available at low cost. Development in this country has been more towards establishing an operating technique for control of quality by eliminating objectionable impurities than it has towards quantity and costs.

The Japanese attempts at making sponge iron by the Swedish sagger method were a failure in the Japanese Home Islands owing to the fact that they used poor-grade ores and coals and consequently produced poor-grade iron. In Manchuria, where rich ore and good coal were available, they produced high-grade sponge iron comparable with that made in Sweden. This venture probably will continue during peacetime.

The use of electric furnaces for smelting iron ores does not come under sponge iron but is mentioned to show the extent of Japanese efforts to supply the wartime demand for iron and steel. The Kikuchi electric-resistance furnace was suitable for Japanese conditions of cheap labor and low-cost electric power. The product was a sort of cast iron suitable as melting stock in electric furnaces. The process may find application in this country on refractory ores, such as titaniferous magnetites.

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The Japanese adoption of sponge iron and other methods of supplying more iron for its war machine was one of the exigencies of war that may survive in peacetime owing to Japan's position as a "have-not" industrial nation. Without its empire, and relying on the meager iron-ore resources of the Home Islands, Japan may continue and expand the use of such methods of production of iron. The degree of success of its past and future efforts may influence the general attitude towards sponge iron in the United States.

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